
Sustainable Materials and Chemicals for the Next Generation

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I will describe a specific example of a large-scale chemical company's approach to, and progression towards, the development of sustainable chemicals and materials. At this point, it is hypothetical, but, I will sprinkle through it highlights of our work on bioprocess synthesis of 1,3-propanediol, to suggest that this is feasible, that it is being done and that it will be commercialized.

How might biotechnology interact with the chemical industry? The global economy today is a \$50 trillion enterprise; biotechnology is having major impact on at least two sectors. In health care, it is revolutionizing the development of new drugs and therapies, and in agriculture it is affecting crop choices and farming practices. While these effects sometimes cause verbal and intellectual fireworks, no one can doubt that actual change is going on.

IMPACT OF BIOTECHNOLOGY ON CHEMICALS AND MATERIALS:

- Biotechnology is an alternative chemistry
- Biotechnology is complementary to traditional sciences

The chemical industry is divided into four sectors: organics, inorganics, industrial gases, and fertilizers. The higher performance segments, organics and inorganics, are dominant. The organics sector, built on the transformation of carbon, is where biotechnology is likely to have greatest impact by generating new knowledge, new molecules and new functions, leading from new products to new businesses. When that cycle functions effectively, change takes place, almost driven by itself.

Chemistry touches most aspects of human endeavor. Without its benefits, this meeting room would look very different. It would be a structure of bare wood and an inferior form of concrete, and you would be sitting on the floor,

probably only half clothed. In modern life, we use the results of chemistry essentially all day, every day.

The chemical industry has much in common with agriculture. They are mature industries, largely commoditized, facing similar issues. How will the chemical industry change and what will be the economic and scientific forces that impact it? One aspect seems clear, the chemistry of biology is a means toward new knowledge and new business opportunities.

GLOBAL “DRIVERS”

- Needs for food, shelter, and health
- Demographics / developing countries
- Technology: information / biotechnology
- Environmental necessities: local / global
- Business competitiveness

Society wants: “more, better, cheaper and cleaner”

Humanity's basic needs are constant: food, shelter, health. The relative expression of those needs changes with demographics. Fortunately, the global population growth rate is beginning to decline. But the standard of living of 75 percent of humanity still does not approach that of the other quarter. There is a tremendous, unmet need for advantages that we enjoy.

What drives change? Technology has a major impact, both from the information side and the biotechnology side. Environmental necessities are changing. Fifteen or thirty years ago, these were almost always considered to be geographically isolated, local problems: e.g. a chemical plant, food-processing factory, public utility, or a defense facility that had not operated properly. Over the past twenty years, however, environmental issues have become viewed on a broader, even global, scale. Perhaps, the first of these was the CFC/ozone-depletion problem that has been instructive in terms of climate models.

Business competitiveness has a major influence on public thinking. What do people want? People want more and better goods, which they wish were less expensive in order to increase access. And they would like those goods to be produced with less environmental impact than is currently the case.

Biotechnology is highly complex, almost impenetrable for the layman. But from the perspective of chemist, it can be reduced to a simple thought: the primary impact of biotechnology on the chemicals and materials industry will lie in presenting alternative chemical methods based on new knowledge.

This biotechnology-based chemistry must be complementary to traditional chemistry. To polarize the argument in terms of chemistry having to be either “all carbohydrate” or “all petroleum” does the dialogue a major disservice. We have to progress from where we are today to a renewable future, a transition that will combine both raw-material bases.

SUSTAINABILITY: Built on Three Legs

- In markets: greater functionality
- In business: lower costs and investment
- In the world: smaller environmental footprint

In using the word “sustainable” in the title, I meant three things relative to sustainability in the marketplace. (1) People will have new products that make their lives better and that are more attractive to business. (2) Costs and investment will be lower and attractive to business. (3) The environmental consequences will be fewer. If we find opportunities for all three, even if not completely in balance, strong pull will be coupled with strong push, a situation that generally leads to movement and progress.

The next few thoughts describe an example of how biotechnology affects these three elements of sustainability. Since sustainability starts with greater functionality and higher performance, let us begin there.

Recently, DuPont introduced a new polymer, trademarked Sorona® (Figure 1). It is a new form of polyester with many attractive advantages and it is the newest member of a series of synthetic polymers, developed at DuPont, that are in common use: Nylon, Dacron®, Teflon® and Lycra®.

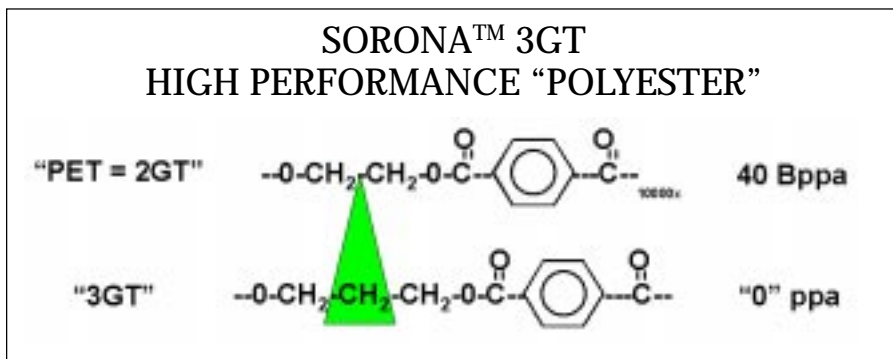


Figure 1.

Polyester is one of the most widely used polymers in the world. About forty billion pounds of polyethylene terephthalate (PET) are produced every year. Today you may drink bottled water from a plastic container, thus using this common form of polyester. PET has remarkable properties: strength, clarity, flexibility, etc. It is easy to recycle by degradation to its virgin chemical components and resynthesis into new, fully performing materials. But it has some shortcomings: fabrics from PET are not terribly comfortable, but rather stiff and scratchy. Therefore, we are making a new polyester by simply adding one extra CH_2 , which presents a whole new opportunity and I will show you why you would want this material.

Traditional polyester, PET, is a long linear structure. The other polyester, PBT, that has some volume in the marketplace, is also relatively long and linear. In contrast, the Sorona® form has a kink in it (Figure 2), which allows the molecules, as organized in polymer, to act like a coiled spring. Instead of being a stiff piece of wire, the coils let the material stretch and recover; so they are softer and return to their original shape.

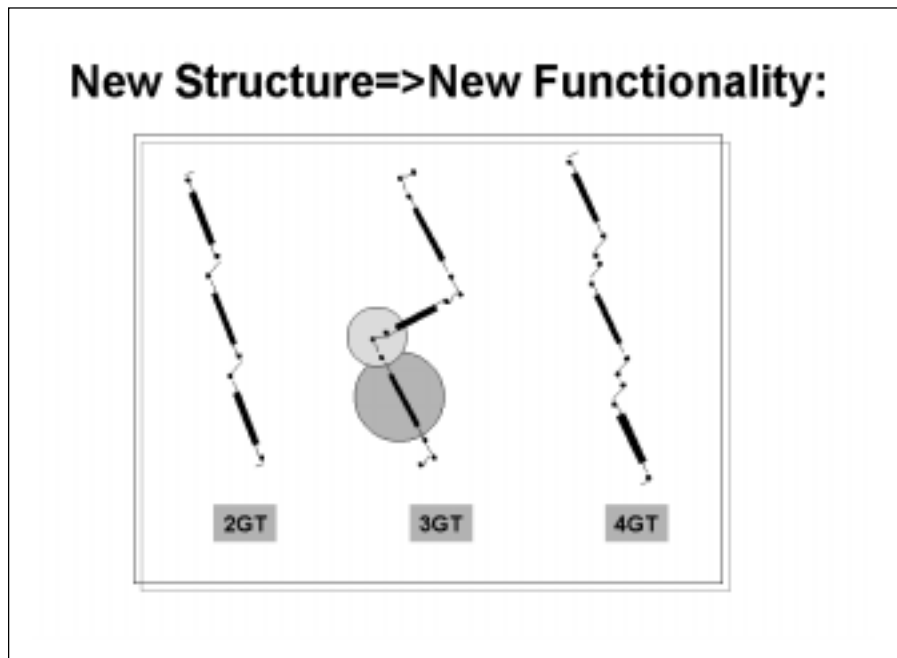


Figure 2

When you flex your elbow while wearing a long-sleeved blouse or shirt, or sit in a car, or put a heavy weight on a carpet: you are stretching or crushing the textile materials. Of course, you want those materials to return to their original size and shape when you remove the strain. Sorona® can be stretched up to 20 percent and return to its original shape, whereas conventional polyesters and nylon can be stretched only to 3, 7, or 10 percent and return to the original length (Figure 3).

Sorona® brings with it additional properties. It takes on dyes easily in an environmentally friendly way, is stain resistant, etc. — properties you are glad to have in materials you use.

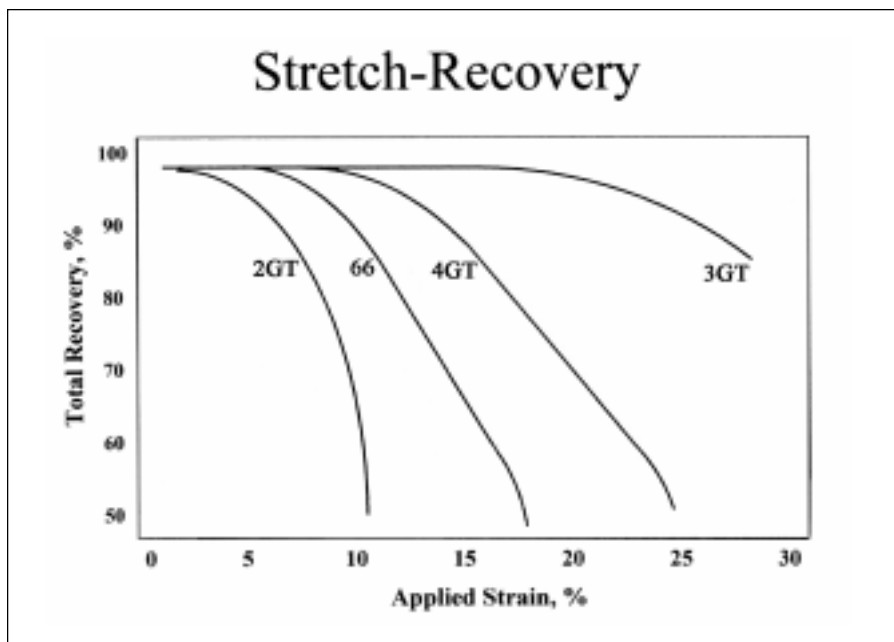


Figure 3

The second leg of sustainability is reduced cost and investment. The new biotech applications utilize alternative feedstocks, and multiple chemical reactions are possible literally in a single reactor. That reactor is a microbe, enabling process simplification and operation-cost reductions.

We are building one half of the Sorona® molecule from corn and the other half from petroleum. The petrochemical is terephthalic acid, which we combine with the new corn-based fermentation product, the oxy-chemical 1,3-propanediol. Thus, Sorona® utilizes the best of both worlds: a low-cost material from petrochemical feedstocks and a low-cost oxy-chemical from corn-derived glucose: a combining paradigm rather than a competing paradigm.

An effective biocatalyst was designed. By combining some genes from yeast, for conversion of glucose to glycerol, with genes from a bacterium, for conversion glycerol to 1,3 propanediol, we built a new microorganism (Figure 4). This is a complex, but highly specific process. Returning to the broader view, these biocatalysts let us go beyond traditional chemical catalysts and their hydrocarbon feedstocks to a whole new set of catalysts, providing the chemist and the chemical engineer with a much broader range of processes and starting materials.

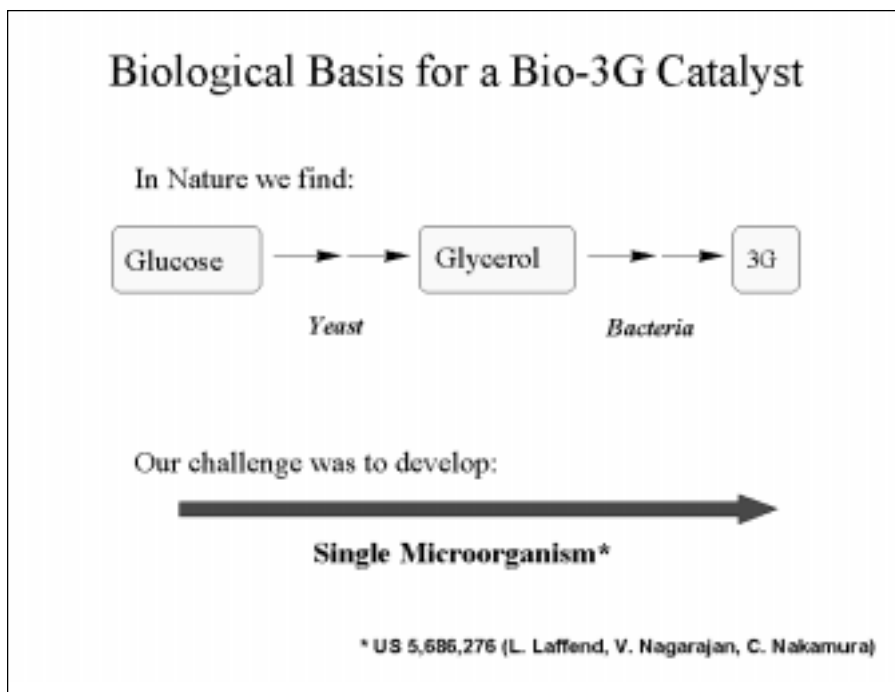


Figure 4

We can make biological catalysts, multiply them through fermentation processes, and separate pure products to derive new sets of chemicals, polymers and fibers largely unknown in the world today.

As an example, in our collaborative work with Genencor International, we have constructed a microorganism that makes levels of 1,3-propanediol even higher than for ethanol in current fermentation processes.

The last aspect of sustainability is environmental impact. Two hundred and fifty years of industrialization have forced the atmosphere out of equilibrium, clearly necessitating careful consideration of the consequences. Agriculture and forestry provide perhaps the only opportunities to fix CO₂, capture nearly free energy from sunlight, and produce plant matter to feed fermentations for new commercial products.

To summarize, we need (1) products of greater functionality to give greater value, (2) processes that operate at lower costs with lower investments, and (3) combinations of products and their processes that achieve a smaller environmental footprint that insures our future.